Thermal Analysis of Interior Permanent-Magnet Synchronous Motor by Electromagnetic Field – Thermal Linked Analysis

Daesuk JOO[1,2], Ju-hee CHO[1], Kyungil WOO[2], Byung-taek KIM[3] and Dae-kyong KIM[1]
[1]Korea Electronics Technology Institute (KETI), Gwangju, 500-480, South Korea
[2]Pukyong National University, Busan, 608-737, South Korea
[3]Kunsan National University, Jeonbuk 573-701, South Korea
Einstein@keti.re.kr

Abstract — Interior permanent-magnet (IPM) synchronous motor possess special features. The high temperature, due to losses, can damage the windings' insulation and may cause demagnetization of permanent-magnet. Therefore, thermal analysis of the motor is a necessity. In this paper, electro-magnetic field – thermal linked analysis of IPM synchronous motor is presented. First the electromagnetic field and thermal analysis are coupled in steady state. Then, the average losses are used to run transient thermal analysis. Thermal analysis is based on the heat transfer model. The heat source of motor is losses. Both experimental results and simulations show that the proposed electromagnetic field – thermal linked analysis is able to reliable predict the temperature variation of IPM synchronous motor.

I. INTRODUCTION

Interior permanent-magnet (IPM) synchronous motors possess special features for adjustable-speed operation which distinguish them from other classes of ac machines. They are robust high power density machines capable of operating at high motor and inverter efficiencies over wide speed ranges, including considerable ranges of constant-power operation [1].

An accurate prediction of the motor thermal performances at the design stage is a necessity [2]. Limits to the rating of electrical machines are set by the maximum permissible temperature for insulation [3]. The high temperature can damage the windings' insulation and may cause demagnetization of permanent-magnet. Therefore, thermal analysis is an important in the design of the IPM synchronous motor.

In this paper temperature prediction of IPM synchronous motor is simulated using a commercially available software package. Thermal analysis is based on the heat transfer thermal model and the result of electromagnetic field analysis. A simple heat transfer thermal equivalent circuit is presented. The losses can be determined from an electro-magnetic field simulation. The heat generation source of motor is joule loss and iron loss. The results from simulations have been compared with experimentally measured temperature data.

II. ELECTROMAGNETIC FIELD – THERMAL LINKED ANALYSIS

The motor used in the analysis is interior permanent-magnet synchronous motor without cooling system (7.5 kW, 65Vrms, 300 Hz, 12 poles).

The electromagnetic field - thermal linked analysis has been simulated in the following assumptions.

1) Temperature dependent parameters are constant.
2) It is assumed interference gaps between parts.
3) It is assumed negligible radiation.
4) It is assumed free convention.
5) Initial temperature was set to 25 ℃.
6) The only heat source is joule loss and iron loss.

The analysis flow is described below.

1) Electromagnetic field analysis and thermal analysis are coupled in steady state analysis.
2) The average losses are used to run transient thermal analysis.

Table 1 shows the average losses obtained from an electromagnetic field simulation.

All the thermal parameters (e.g., electric conductivity of the magnet, coil resistance, etc) are not dependent on temperature. Table 2 shows the thermal properties of parts.

The accuracy of a motors thermal performance prediction is dependent upon the estimate of the many thermal contact resistances within the machine (e.g., stator lamination to housing, slot-liner to lamination, etc). A contact resistance is due to imperfections in the touching surfaces and is a complex function of material hardness, interface pressure, smoothness of the surfaces, and air pressure [4].

The thermal resistance for conduction in a plane wall is [5]

$$R_{t,cond} = \frac{L}{kA}. \tag{1}$$

Where L is an effective interface gap, k is the thermal conductivity and A is the cross-section area of the direction of heat transfer.

TABLE 1
AVERAGE LOSSES

Joule loss		Iron loss	
coil	magnet	stator	rotor
32 W/phase	34 W	179 W	14 W

TABLE 2
THERMAL PROPERTIES OF MATERIALS

Parts	Thermal conductivity [W/m ·℃]	Specific heat [J/Kg·℃]	Density [Kg/m^3]
Stator & Rotor	23	460	7700
Magnet	20	460	7600
Shaft	20	1100	7860
Coil	380	380	4000
Housing	167	896	2700
Air	0.027	1050	1.205

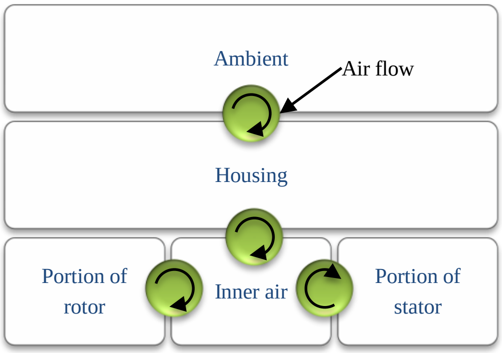

Fig. 1. Convection heat transfer mode

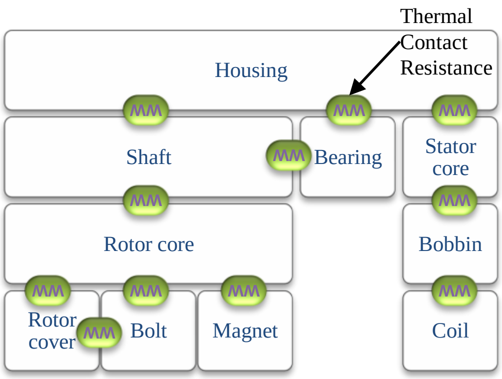

Fig. 2. Conduction heat transfer mode

Convection heat transfer may be classified according to the nature of the flow [5]. In this case it is presumed pure free convection in fig. 1.

Conduction heat transfer may be used for heat flow model as shown in fig. 2.

III. EXPERIMENTAL AND SIMULATIONS RESULTS

The prototype IPM synchronous motor test has been performed at rated power. The experimental temperature data of the housing and coil have been measured by thermocouples.

The main problem is to predict the free convection heat transfer coefficient. These are based on the housing geometry length, fluid material properties (air) and the air velocity [2]. Typical value of the heat transfer coefficient for free convection is in the range 2 to 25 [W/m^2·°C] [5]. For this simulation two models have been considered:

- Model 1: In this model the free convection heat transfer coefficient is 10 [W/m^2·°C].
- Model 2: In this model the free convection heat transfer coefficient is 20 [W/m^2·°C].

Fig. 3 and fig. 4 show coil and housing average temperature, respectively.

The coil average temperature simulated by model 1 is within the -5 °C measurement data. The accuracy of the housing temperature prediction is not so good. This is not too bad an outcome as the coil is a more critical part in terms of motor life [2].

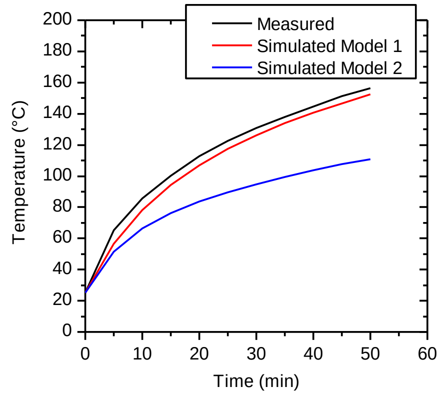

Fig. 3. Coil temperature comparison

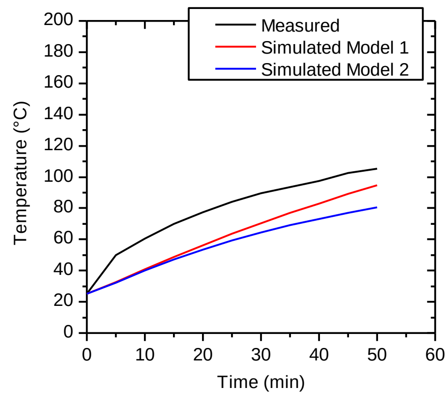

Fig. 4. Housing temperature comparison

IV. CONCLUSION

In this paper, electromagnetic field – thermal linked analysis of IPM synchronous motor based on the heat transfer method was proposed. Both experimental results and simulations show that the proposed electromagnetic field – thermal linked analysis is able to reliable predict the winding temperature variation of IPM synchronous motor.

The proposed analysis is expected to help improve the thermal performance of IPM synchronous motor.

V. REFERENCES

[1] Jahns, Thomas M.; Kliman, Gerald B.; Neumann, Thomas W.; , "Interior Permanent-Magnet Synchronous Motors for Adjustable-Speed Drives," *Industry Applications, IEEE Transactions on* , vol.IA-22, no.4, pp.738-747, July 1986.

[2] Boglietti, A.; Cavagnino, A.; Staton, D.A.; , "Thermal analysis of TEFC induction motors," *Industry Applications Conference, 2003. 38th IAS Annual Meeting. Conference Record of the* , vol.2, no., pp. 849- 856 vol.2, 12-16 Oct. 2003.

[3] Tavner, P.J.; , "Review of condition monitoring of rotating electrical machines," *Electric Power Applications, IET* , vol.2, no.4, pp.215-247, July 2008.

[4] Staton, D.; Boglietti, A.; Cavagnino, A.; , "Solving the more difficult aspects of electric motor thermal analysis," *Electric Machines and Drives Conference, 2003. IEMDC'03. IEEE International* , vol.2, no., pp. 747- 755 vol.2, 1-4 June 2003.

[5] Incropera, Fundamentals of Heat and Mass Transfer, 6th ed., Wiley.

[6] Boglietti, A.; Cavagnino, A.; Pastorelli, M.; Staton, D.; Vagati, A.; , "Thermal analysis of induction and synchronous reluctance motors," Industry Applications, IEEE Transactions on , vol.42, no.3, pp. 675-680, May-June 2006.